

Photovoltaic (PV) Energy as Recharge Source for Portable Devices such as Mobile Phones

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Abstract

This paper presents opportunities to recharge portable devices, in particular mobile phones, with photovoltaic (PV) energy. Conventional available PV chargers suffer from the disadvantage of long charging times, which are unacceptable for the users of these types of electronics. We review approaches to overcome this drawback and discuss possibilities to shorten the recharging time. We present efficient system configurations, which help that PV energy becomes part of our daily life.

Index Terms: Mobile phones, Photovoltaics, Portable devices, Recharge.

I. INTRODUCTION

Mobile phones are part of our daily life. Nowadays we use smartphones, which include a huge variety of features such as navigation, highspeed internet access, and high resolution cameras with flash lights. Unfortunately, these powerful functionalities are also power hungry. Some days the capacity of the battery cannot cope with our requirements and we need to recharge our mobile phone during the day [1]. Hereby, we can use renewable energy [2].

Photovoltaic (PV) energy is the most promising one within these types of energy sources, because of its high power density [3]. However, there are some important aspects, which we have to consider along the use of photovoltaics. At first we have to respond to the variable output power. The performance highly depends on the ambient conditions such as the solar radiation level (λ [W/m²]), the cell temperature (T_c [K]), and the operating point of the photovoltaics [4].

The motivation for our research comes from the overall increased energy consumption, which we have within our society today. The rise on energy demand continues in future significantly [5]. Nowadays we are using various portable devices such as tablets, netbooks, or MP3-player, for example, beside smartphones. These devices are all powered by batteries and contribute to the increase on energy demand. It is also possible to recharge these type of devices with PV energy rather than with energy gained from fossil energy resources such as oil or coal [2], [5].

This paper is organised as follows: Section II provides information to understand PV energy as an energy source. We analyse the system structure of conventional available PV chargers and their drawbacks in Section III. Afterwards, Section IV presents management strategies of PV energy and special requirements for portable devices. In Section V, we discuss possible system structures to improve PV chargers, while we summarise and conclude in Section VI.

II. OUTPUT BEHAVIOUR OF PV ENERGY

A. Overview

Photovoltaics demonstrate a nonlinear output behaviour. The I-V (Current-Voltage) curve represents the possible output power, which we can obtain at different operating voltages (see Fig. 1). We see that there is only one point given on the entire I-V curve, in which the output power achieves the maximum; referred as the maximum power point (MPP) [4]. Commonly, we use microcontrollers to control PV cell or arrays and to set the operating voltage (V_{op}) to the voltage in the MPP (V_{mpp}) [3].

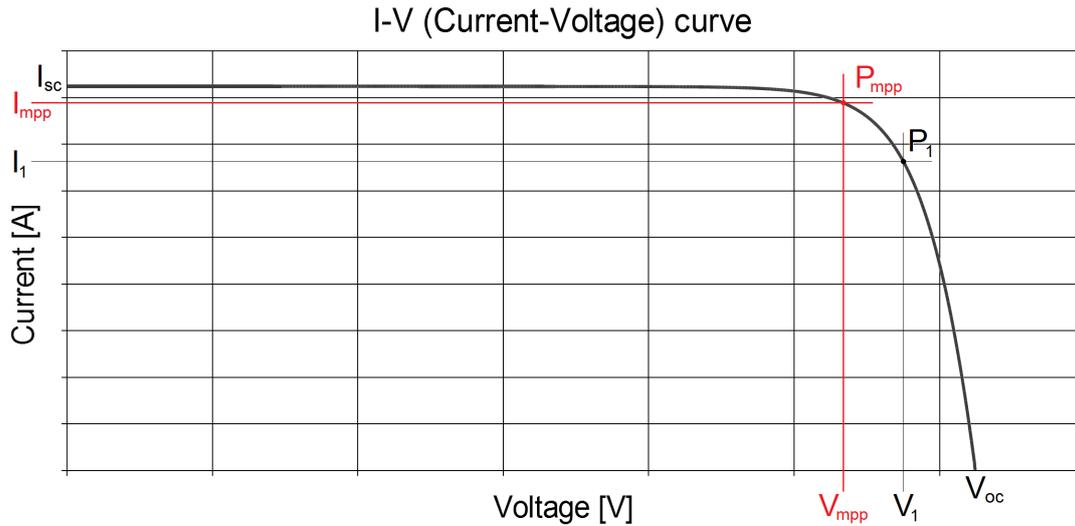


Fig. 1. I-V curve with important points and parameters (arbitrary units)

For example, if we choose the voltage V_1 , we obtain the power P_1 , which is less than the power in the MPP (P_{mpp}); summarised as follows:

$$\begin{cases} P_{out} = P_{mpp} & \text{if } V_{op} = V_{mpp} \\ P_{out} = P_1 < P_{mpp} & \text{if } V_{op} = V_1 \end{cases}$$

Two important parameters are the open-circuit voltage V_{oc} and the short-circuit current I_{sc} to describe the electrical characteristics of photovoltaics [4]. We can obtain these parameters, which depend on λ and T_c , usually from the datasheet of the manufacturer of the photovoltaics.

B. Management of PV energy

The position of the MPP changes according to different solar radiation levels and temperatures. Hence, we need to track the MPP by the help of a maximum power point tracking (MPPT) unit. In general, this unit includes sensors, a power converter, and a microcontroller unit (MCU) (see Fig. 2). The microcontroller modifies the operating voltage (V_{op}) based on the information of the sensor(s) and ensures operating at or close to the MPP. However, there are numerous approaches available to carry out MPPT [6]. They differ in:

- sensed parameters (voltage, current, solar radiation, temperature),
- control complexity,
- power converter structure,
- convergence speed,
- periodic tuning.

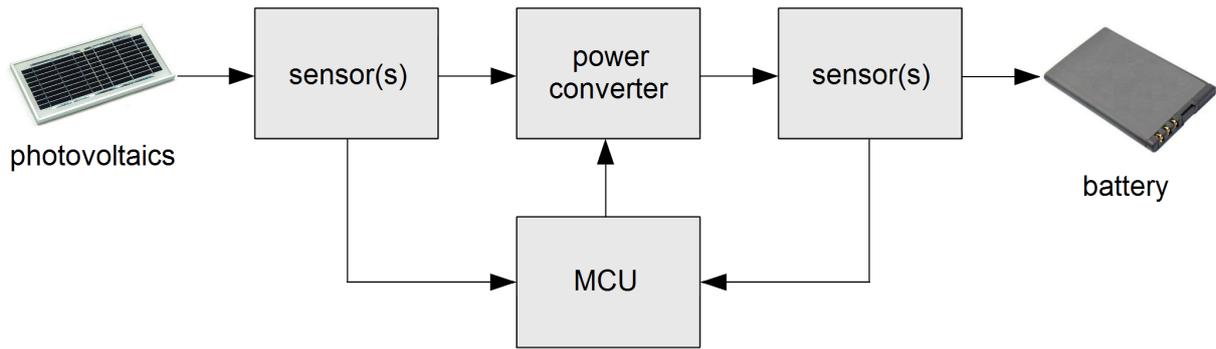


Fig. 2. Basic structure of the system

III. CONVENTIONAL PV CHARGERS

A. System structure

In this paper, we focus on PV chargers for mobile phones. The system structure of these type of chargers is simpler than the structure, which we have discussed previously. The main difference is that we do not have a MCU within the system and thus, no MPPT is implemented. The following picture shows the components of the Patona 7-in-1 PV charger, which we take as an example for conventional PV chargers, which are available today on the market. Here, either the USB or PV is connected over a diode with the battery.

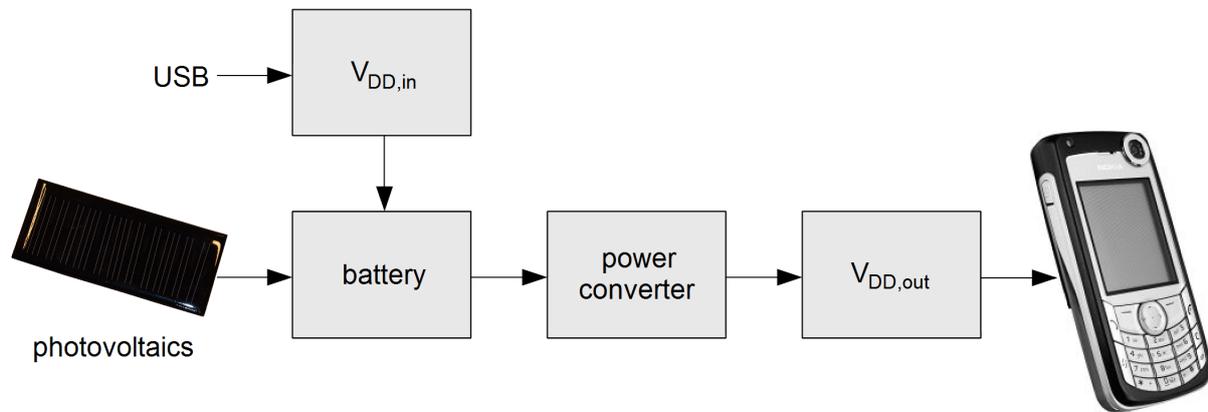


Fig. 3. Components of the Patona 7-in-1 PV charger

The lithium-polymer (Li-poly) battery of the PV charger has a capacity of 1000 mAh and a voltage level of 4.2 Volt. We can charge the battery via the USB interface with a voltage of 5 Volt ($V_{DD,in}$) and a current of about 500 mA. Similarly, the photovoltaics of the system provide 5.5 Volt, but only 80 mA on maximum current according to the manufacturer of the PV charger. On the output side we can obtain a voltage of 5.5 Volt ($V_{DD,out}$) and a charging current of 300 up to 500 mA depending on the mobile phone, which we would like to charge.

The lithium-ion (Li-ion) battery of the smartphone within our research has a capacity of 1070 mAh [2]. Typically, smartphones include batteries with a capacity of about 1500 mAh [1] and nowadays, even with a capacity greater than 2000 mAh to support all their features with enough power. We conclude that the battery of the PV charger is too weak to give a full recharge to smartphones.

B. Photovoltaics of the system

Our focus lies on the photovoltaics of the system, since we want to charge our mobile phones with renewable energy. It is obvious that the PV cell provides to less output current so that we can charge mobile phones directly. Hence, we have to store the gained PV energy in the li-poly battery. However, the battery as a buffer will lower the performance of the system, because we have to consider its degree of efficiency ($\eta_{battery}$).

We measured the output behaviour of the photovoltaics (see Fig. 4). The ambient conditions were $\lambda = 700 \text{ W/m}^2$ and $T_c = 298.1 \text{ K}$ ($25.1 \text{ }^\circ\text{C}$). Table I summarises the measurement results. The standard test conditions (STC) for photovoltaics are usually $\lambda = 1000 \text{ W/m}^2$ and $T_c = 298 \text{ K}$ ($25 \text{ }^\circ\text{C}$). If we refer our data to STC, we see that the 80 mA output current are only possible if $\lambda > 1000 \text{ W/m}^2$, which is a very high solar radiation level for Scandinavia. However, we see that we operate close to the MPP. The difference between the MPP (P_{mpp}) and the operating power point (P_I) is 2.59 % if $\lambda = 700 \text{ W/m}^2$.

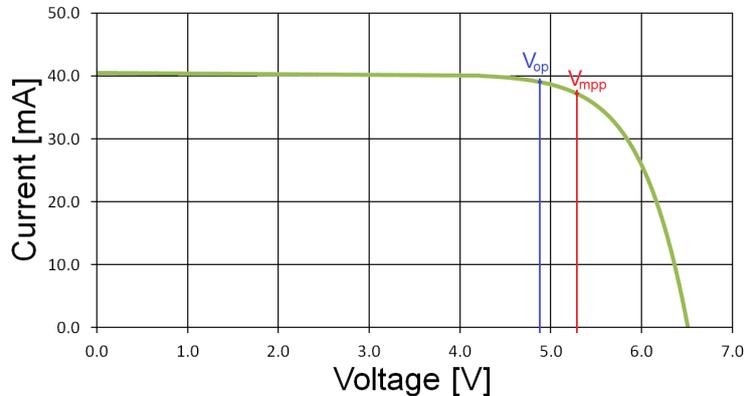


Fig. 4. I-V curve of the Patona 7-in-1 PV charger

TABLE I
MEASUREMENT RESULTS FOR THE PHOTOVOLTAICS OF THE PATONA 7-IN-1 PV CHARGER

Parameter	Value	Parameter	Value
P_{mpp} [mW]	196.6	P_I [mW]	191.5
V_{mpp} [V]	5.29	V_I [V]	4.92
I_{mpp} [mA]	37.14	I_I [mA]	38.93
V_{oc} [V]	6.51	I_{sc} [mA]	40.5

IV. POSSIBLE MPPT TECHNIQUES FOR MOBILE PHONES

A. General

At least 19 distinct MPPT algorithms have been proposed over the last decades [6]. The range of proposed methods goes from using obvious circumstances until using a lot of creativity. Furthermore, the approaches differ in the required amount and type of sensors, the efficiency, costs and other criteria as already discussed previously. Unfortunately, due to this large variety on MPPT algorithms, we cannot say right away, which methods are more effective than other ones [6]. However, we can reduce the amount of possible MPPT algorithms for mobile phones, because it is difficult to sense the solar radiation level or temperature with this type of devices, for example [2].

B. Perturb and observe (P&O) algorithm

We can consider the P&O algorithm as one of the most popular ones. The MCU varies the duty cycle of the dc/dc converter to change the operating voltage (V_{op}) of the PV array. Thereby, we move the present operation point (P_1) and to reach the MPP (P_{mpp} and V_{mpp}). Fig. 5 illustrates the situation on hand of the P-V (Power-Voltage) curve. This working principle effects the current level (I_l) at the same time. For example, if we increase the voltage, the power increases. However, if we decrease the voltage, we decrease the power as well [6].

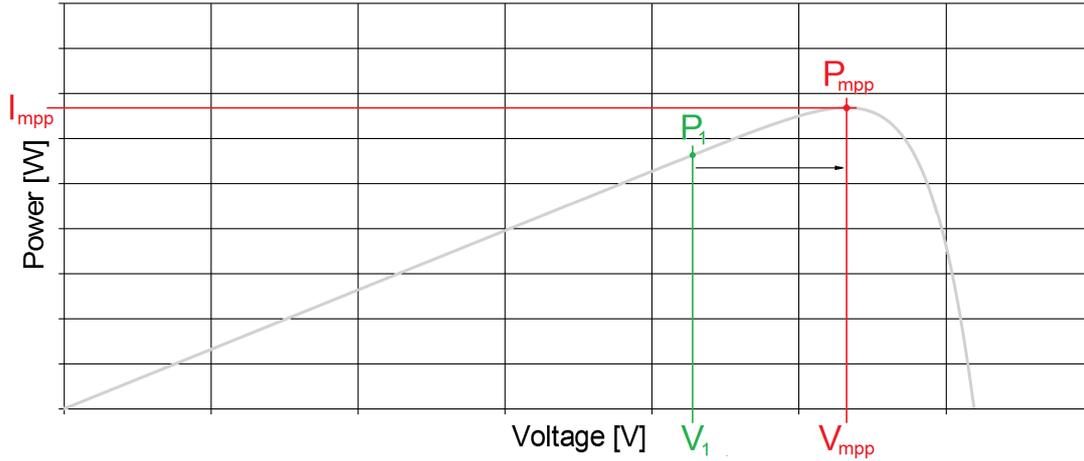


Fig. 5. Working principle of the P&O algorithm (arbitrary units)

We do not know the exact voltage in the MPP (V_{mpp}). This means that we do not know if our present operating point (P_1) is located on the left- or right-hand side of the MPP. Hence, we need to observe if our changes have a positive or negative impact on the output power. Therefore, we measure the voltage and current on the output side. As result from this observation, we consider the perturbation in the next iteration. Table II summarises possible situations for the P&O algorithm [6].

TABLE II
WORKING PRINCIPLE OF THE P&O ALGORITHM

Perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

C. Considerations for the P&O algorithm within mobile phones

The P&O algorithm can cause problems if the solar radiation level changes quickly (see Fig. 6). We start in point A and perform a perturbation ΔV . We end up in point B if the ambient conditions changes and in point C if the ambient conditions stay unchanged. In point C we make the right decision and reverse the perturbation due to the decreased power. In point B we obtain an increase in power and keep the size and sign of perturbation. If the solar radiation level continues to increase, we continue to move away from the MPP. This

makes the P&O algorithm less suitable for mobile phones where we expect fast changing ambient conditions, for example, if users attach their photovoltaics to back bags.

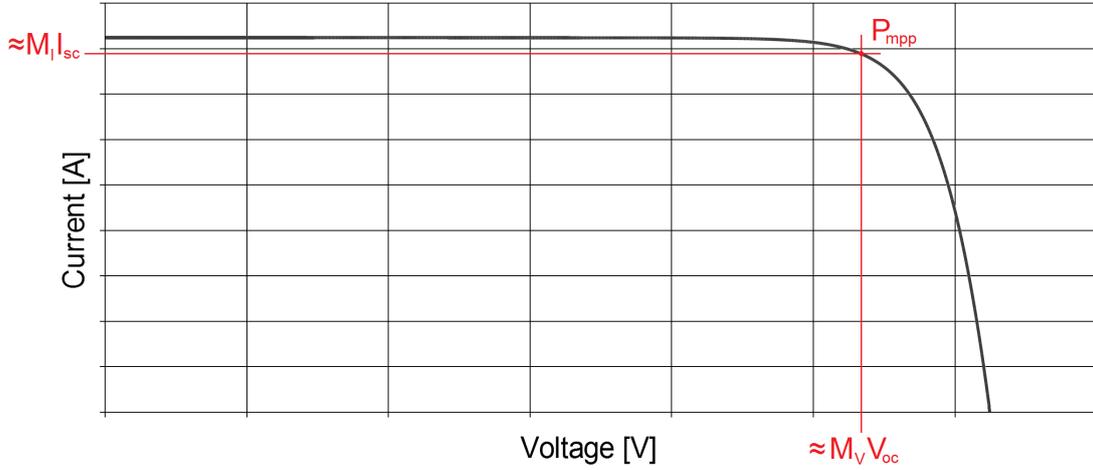


Fig. 6. Problem of the P&O algorithm with fast changing ambient conditions (arbitrary units)

D. Voltage-based MPPT (VMPPT) and current-based MPPT (CMPPT)

There is a strong correlation between the voltage in the MPP (V_{mpp}) and the open-circuit voltage (V_{oc}), even though we obtain changes in the solar radiation level and temperature. We can make use of this relationship and assume the operating voltage (V_{op}) as a fraction of V_{oc} . We consider this fraction by using the factor M_V , in case of VMPPT (see Equation (1) and Fig. 7). Similarly, we can use a fraction of the short-circuit current (I_{sc}) and a factor M_I to establish CMPPT [6],[7] (see Equation (2) and Fig. 7).

$$V_{op} = M_V V_{oc} \approx V_{MPP} \tag{1}$$

$$I_{op} = M_I I_{sc} \approx I_{MPP} \tag{2}$$

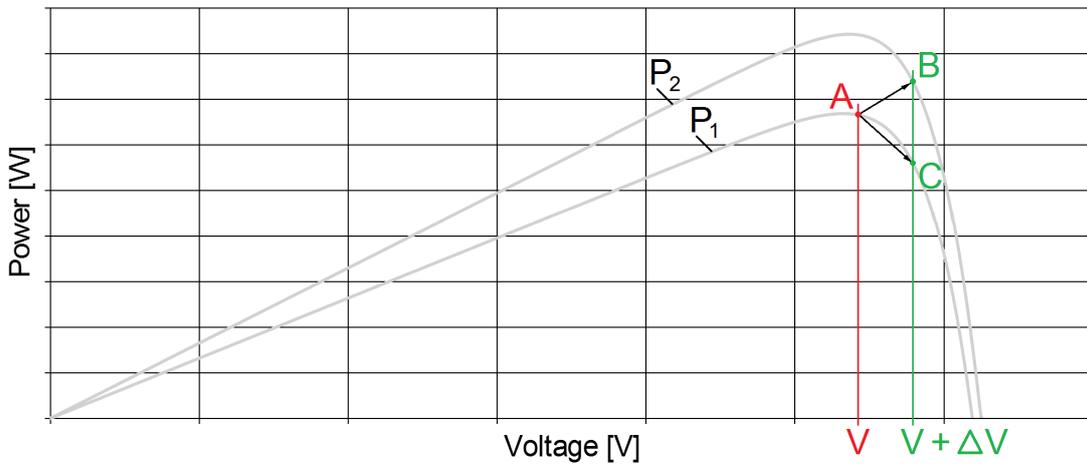


Fig. 7. Working principle of VMPPT and CMPPT (arbitrary units)

Since we do not know the open-circuit voltage (V_{oc}) in the case of VMPPT, or the short-circuit current (I_{sc}) if we use CMPPT, which we have at the moment under certain ambient conditions, we have to measure either one of them. The value of the factor M_V (as well as of M_I) depends on the used PV technology. Typical values for M_V range for from 0.7 to 0.8, and for M_I from 0.75 to 0.95. In general, it is easier to measure V_{oc} than I_{sc} . The fractions of V_{oc} and I_{sc} are only assumptions; in reality we never operate exactly in the MPP. However, we need one sensor less in comparison to the P&O algorithm [6],[7].

V. IMPROVED PV CHARGERS FOR MOBILE PHONES

A. Required charge speed by the user

Studies were carried out about the charging behaviour of smartphone users as in [1],[8]. The study in [1] shows that mobile phones are often charged within a short period of time, which is less than 30 minutes. The majority of users prefer the AC adapter against the universal serial bus (USB) interface. Table III summarises the voltage levels, charging currents and available charging powers of these two interfaces. Furthermore, we verify their possibilities against the conventional PV charger, which we have chosen as an example for those type of chargers. Additionally, we can calculate the charging power, which we can provide to mobile phones within 30 minutes.

TABLE III
PROVIDED CHARGING POWER

Opportunity	Voltage level	Charging current	Available charging power	Charging power in 30 min
AC Charger	up to 6 Volt	up to 900 mA	up to 5.5 Watt	up to 2.25 Wh
USB 2.0	5 Volt	about 500 mA	up to 2.5 Watt	up to 1.25 Wh
PV Charger	5.5 Volt	up to 80 mA	up to 0.44 Watt	up to 0.22 Wh

We conclude that the conventional PV charger provides less than 10 % of the power, which the AC charger provides in the same period of time. In other words, users have to connect their smartphones for over 10 times longer (about 5 hours) to the PV charger to get the same amount of power. We see that the photovoltaics of the PV charger are too weak, even though we assume operating under ideal ambient conditions.

B. Possible structures to improve PV chargers

We can fulfill user requirements if we choose photovoltaics with higher output power, for example of about 5 Watt. If we use PV arrays with an output power level up to 10 Watt, we can also provide enough charging power under non-ideal ambient conditions. The photovoltaics are directly connected with the battery in the case of conventional PV chargers. There is a diode in between the PV cell and the battery (see Fig. 8). It prevents that power goes back from the battery to the photovoltaics, what can be the case if the photovoltaics are shadowed.

It is important that the ratio of V_{oc} and I_{sc} is suitable for this type of connection. For example, if we want to charge our mobile phone via the USB interface ($V_{charge} = 5$ Volt), we can determine suitable levels of the $V_{oc,min}$ by the help of Equation (3). However, this restricts the range of photovoltaics, which we can use for recharging mobile phones. On the other hand, we do not obtain a notable power if V_{oc} is much greater than $V_{oc,min}$. Hence, we need to use dc/dc converters to optimise the degree of efficiency.

$$V_{oc,min} > V_{charge} + V_{diode} \tag{3}$$

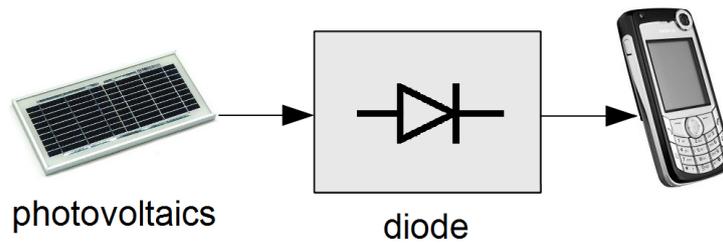


Fig. 8. Direct connection of photovoltaics

If we use dc/dc converters and MCUs we can use a wider range of photovoltaics. We propose using VMPPT as MPPT technique to improve the degree of efficiency. We usually measure V_{oc} periodically. Therefore, we disconnect the dc/dc converter, and we take a loss of power into account. However, we can determine suitable values for a fixed operating voltage (V_{op}), for example, by the help of simulations [9]. Then we do not need to measure V_{oc} and do not need the voltage sensor on the input side. Moreover, we can use mobile phones as microcontrollers [2] (see Fig. 9).

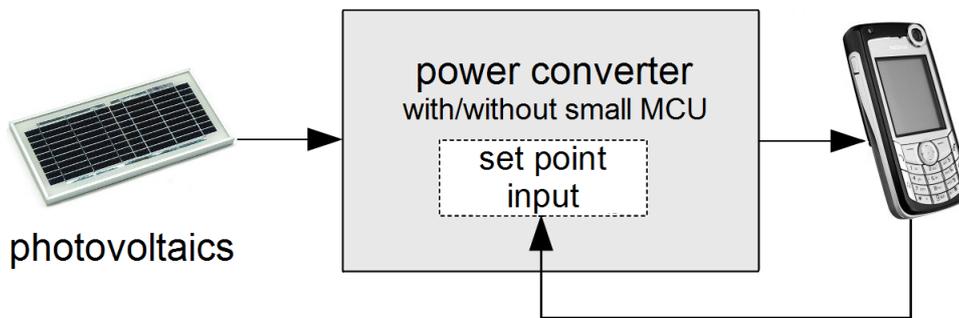


Fig. 9. Proposed connection of photovoltaics with mobile phones

VI. CONCLUSION

We conclude that it is possible to recharge portable devices such as mobile phones with PV energy, but we need to use suitable photovoltaics and system structures to fulfill user requirements. The contributions of this paper are the summary of suitable MPPT techniques for portable devices, the analysis of conventional available PV chargers on the one hand and possible improvements on the system structure to overcome their drawbacks on the other hand.

At the moment conventional PV chargers do not provide suitable recharging times. Hence, we propose system structures with larger photovoltaics with an output power of about 5 Watt and dc/dc converters instead of direct connections. Furthermore, we recommend VMPPT, because it is simply to implement in the case of mobile phones. We lower recharging times with the help of this approach. Additionally, we lower the costs in comparison to conventional PV chargers and make photovoltaics more feasible as an energy source.

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